The transapical approach for aortic valve implantation

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Objective: Percutaneous aortic valve implantation has been performed clinically in high-risk patients with severe aortic stenosis. Transfemoral retrograde valve delivery is limited by concomitant peripheral vascular disease and the size of the delivery system. We report on the alternative transapical approach that allows accurate antegrade placement of a catheter-deliverable aortic valve.

Methods: Over a 2-year period, 26 consecutive patients (84.3 ± 6.5 years) were treated at our center. Transapical aortic valve implantation was performed with 23-mm and 26-mm pericardial valves (Cribier-Edwards; Edwards Lifesciences, Irvine, Calif) mounted on a stainless steel stent. A limited anterolateral incision, in the fifth intercostal space, was used to access the apex of the heart. The valve was crimped, placed into a 24F sheath, and introduced into the left ventricle through purse-string sutures. Fluoroscopy and transesophageal echocardiography were used to guide the catheter across the native valve and to direct deployment of the stent at the level of the annulus. During deployment, the heart was unloaded with extracorporeal support or with rapid ventricular pacing. The average logistic EuroSCORE-predicted risk for mortality was $36.5\% \pm 5.8\%$.

Results: All valves were successfully deployed at the target. On echocardiography, all valves showed good hemodynamic function with only minor paravalvular leakages. The mean transaortic valve gradient was 6 ± 2 mm Hg. Thirty-day mortality was 15% ($n = 4$). One patient died of perforation of the right ventricle and 1 of dissection of the aortic root. There were 2 cases of conversion to open surgery. In 2 patients, the left main stem was partially obstructed by the native valve and required stent angioplasty.

Conclusions: Initial results of the transapical approach are encouraging. Long-term studies and randomized protocols will be required to further evaluate this procedure.

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Aortic valve replacement (AVR) with cardiopulmonary bypass (CPB) is the established gold standard in the treatment of symptomatic severe degenerative aortic stenosis that offers both symptomatic relief and the potential for improved long-term survival.¹ However, because many of the typically elderly patients with symptomatic severe aortic stenosis have significant comorbidities, open AVR with CPB can be associated with an unacceptable perioperative mortality and morbidity. Thus, there is an ongoing attempt to evaluate and to define alternative treatment options for these highest risk patients. Managed medically, symptomatic patients have a poor prognosis and the hope of long-term benefit with balloon aortic valvuloplasty has not been realized owing to a high necessity of reinterventions.²⁻⁵ Still, this technique served as a precursor for the rapidly evolving field of transcatheter-based aortic valve implantation (AVI), which selected centers have recently started to pursue.⁶⁻¹⁰ Percutaneous AVI in humans was first performed as a femoral transvenous procedure with antegrade access to the aortic valve by Cribier and colleagues.⁶⁻⁸ Subsequently, a technically less challenging retrograde femoral transarterial procedure has been reported that can be problematic owing to concomitant peripheral vascular disease as well as the size of the delivery system.^{11,12} Animal developmental work

Abbreviations and Acronyms

- AVI = aortic valve implantation
- TAP-AVI = transapical aortic valve implantation
- AVR = aortic valve replacement
- CPB = cardiopulmonary bypass

with direct balloon catheter implantation of an aortic valve through the left ventricular apex further broadened the spectra of transcatheter based AVI.^{9,10} Recently, the first successful clinical case in which this approach was used to implant an aortic valve without CPB was published.¹³ The purpose of the current investigation was to report our initial clinical experience in 26 consecutive patients who underwent antegrade placement of a catheter-deliverable aortic valve (Cribier–Edwards; Edwards Lifesciences, Irvine, Calif) through the left ventricular apex at our institution.

Patients and Methods

Patient Selection: Inclusion criteria

High-risk patients with severe symptomatic aortic stenosis and an aortic valve orifice area of 0.8 cm² or less were selected for the purpose of this study. High risk was defined by a logistic EuroSCORE predicted risk for mortality greater than 20%.¹⁴ Additional inclusion criteria were an age of 75 years or older, echocardiographically measured aortic annulus diameter of 24 mm or less, as well as symmetrically distributed calcification of the stenotic native aortic valve cusps. The novel therapeutic option of transapical aortic valve implantation (TAP-AVI) was discussed extensively with all patients considered suitable for inclusion in the study, focusing on the overall risk profile of the individual patient, on the preoperative activities of daily living, the motivation of the individual patient, and on the ongoing results of the new technique. Applying these guidelines, we treated 26 consecutive patients (84.3 ± 6.5 years) between February 2006 and February 2008 at the Hospital of the Johann Wolfgang Goethe University, Frankfurt/Main, Germany, with an average logistic EuroSCORE predicted risk for mortality of 36.5% ± 5.8%. The study was approved by the institutional review board and informed consent and permission for the release of information were obtained from each patient. Patient demographics are summarized in Table 1.

Patient Selection: Exclusion criteria

The presence of one or more of the following comorbidities was considered a contraindication for TAP-AVI: echocardiographically measured aortic annulus diameter of more than 25 mm, noncalcified aortic stenosis, subvalvular aortic stenosis, bicuspid aortic valve, intracardiac thrombus or vegetation, endocarditis, untreated symptomatic coronary artery disease, myocardial infarction within less than 1 month, ejection fraction less than 20%, recent stroke, and hypertrophic obstructive cardiomyopathy.

Procedure

All operations were performed in a specially equipped angiography suite that fulfills the standards of a hybrid operating room. A mono-

plane fluoroscopic angiography system (Axiom Sensis; Siemens, Munich, Germany) was used. Fluoroscopy is important for allowing an optimal delineation of the level of the aortic annulus in relation to the aortic sinuses, along with imaging of the coronary ostia. Besides standard hemodynamic monitoring, transesophageal echocardiography and CPB were routinely available. Transesophageal echocardiography was used for repeated measurements of aortic annular diameters. Using an oversizing technique, we chose a valve size that was 2 to 3 mm larger than the echocardiographic annular measurements to achieve good contact with the aortic annulus and to minimize the risk of paravalvular leaks.

The valve was prepared for transapical antegrade delivery under sterile conditions in the operating room. The delivery catheter was flushed with a heparinized saline solution. The deployment balloon was primed with a mixture of saline and contrast that was free of air. The valve was crimped onto the deployment balloon so that it was equidistant between two radiopaque markers and was able to be passed through the 33F transapical delivery sheath. All valve deployments were performed with standard volumetric inflation of the balloon. Fluoroscopy and transesophageal echo were used to guide the catheter across the native valve and direct deployment of the stent at the level of the annulus. During deployment, the heart was unloaded with CPB or with rapid ventricular pacing. The Cribier–Edwards prosthesis is a pericardial xenograft mounted on a stainless steel stent and is available in two sizes: 23 mm and 26 mm (Figure 1).^{7-9,14}

Patients were placed in a supine position. The femoral vessels were exposed, either for cannulation for CPB or to place a venous

TABLE 1. Demographic characteristics of study population

No. of patients	26
Age (y)	84 ± 7
Gender (male)	6 (23%)
Ejection fraction < 30%	5 (19%)
History of tobacco use	18 (69%)
Respiratory dysfunction/COPD	8 (31%)
Diabetes mellitus	8 (31%)
Renal failure	10 (38%)
Renal failure on dialysis	2 (8%)
Coronary artery disease*	11 (42%)
Presence of mitral incompetence ≤ II° †	5 (19%)
Recent cardiac decompensation	8 (31%)
Peripheral vascular disease	4 (15%)
Porcelain aorta	3 (12%)
NYHA class	3.5 ± 0.4
Previous cardiac surgery	3 (12%)
Aortic valve orifice area (cm ²)	0.6 ± 0.1
Previous stroke	3 (12%)
Pulmonary hypertension	7 (27%)
Arrhythmia	8 (31%)
EuroSCORE predicted risk for mortality‡	36.5% ± 5.8%

COPD, Chronic obstructive pulmonary disease; NYHA, New York Heart Association; n (%) is listed for categorical variables; mean ± 1 standard deviation for normally distributed continuous variables. *Diffuse coronary artery disease without any indication for surgical treatment or status-post percutaneous transluminal coronary angioplasty; †no indication for concomitant surgical valve repair; ‡according to logistic EuroSCORE calculations.

Figure 1. Edwards SAPIEN THV, a xenograft consisting of 3 bovine pericardial cusps with Therafix treatment mounted in a balloon-expandable stainless steel stent.

and an arterial guidewire (off-pump procedure) for safety reasons in order to be prepared for fast cannulation. In addition, a femoral arterial sheath (6F) was inserted and an aortic root pigtail catheter for angiographic visualization was placed. High-dose heparin (300 IU/kg) was given for on-pump cases, and low-dose heparin (5000 IU) was used for off-pump procedures, with a target activated clotting time of 180 to 200 seconds. A limited anterolateral incision (5–7 cm), in the fifth intercostal space, was used to access the apex of the heart. A bipolar epicardial pacing wire was placed and tested. Two U stitches with Teflon felt pledgets using 3-0 Prolene polypropylene (Ethicon, Inc, Somerville, NJ) were placed in the apex of the left ventricle. They served as a purse string for linear closure of the left ventricle at the end of the procedure. The left ventricular apex was punctured and a soft guidewire passed in an antegrade fashion across the stenotic aortic valve under fluoroscopic and echocardiographic guidance. A 14F soft sheath was introduced and positioned across the aortic valve. A 03500 super-stiff guidewire (Amplatz Super Stiff; 260 cm, Boston Scientific, Natick, Mass) was then positioned across the aortic arch and placed into the descending aorta. The sheath was partially withdrawn and a 20-mm balloon valvuloplasty catheter positioned under fluoroscopic and echocardiographic guidance. Balloon valvuloplasty was performed once during a brief episode of rapid ventricular pacing (150 beats/min). The balloon catheter and apical sheath were withdrawn and a 33F transapical delivery sheath inserted bluntly. The valve was then inserted with the specific application system. After careful de-airing of the sheath, the valve was positioned so that the annulus bisects the stent. Fluoroscopic and echocardiographic imaging was used to position the valve, and single shot aortic root angiography was used to confirm the intra-annular position below the coronary ostia. During a second brief episode of rapid ventricular pacing, the valve was almost

instantaneously implanted with rapid balloon inflation. Rapid pacing was then stopped to allow for hemodynamic recovery. Repeat dilatation was indicated in the presence of moderate paravalvular leakage. Valve function was immediately assessed by angiographic and echocardiographic visualization. The transapical sheath was removed and the apex securely closed with the purse-string sutures. CPB was weaned, if necessary, the cannulas removed, and protamine administered. Intercostal blockade was performed with ropivacaine. The pericardium was partially closed over the apex and a left lateral chest tube inserted. The incision was closed in a standard fashion. Postoperative images of TAP-AVI are displayed in Figure 2. Postoperative device-specific medical therapy consisted only of aspirin 100 mg daily.

Statistical Evaluation

For the purpose of this report, no specific statistical evaluations were deemed necessary. Continuous data are reported as mean $\pm$ 1 standard deviation or median with intraquartile range if appropriate. Categorical variables are expressed as percentages.

Results

Perioperative Results

In 15 patients (58%) TAP-AVI was performed after cannulation of the femoral vessels. With increasing experience, however, femoral cannulation only was performed without CPB ($n = 4$, 15%). Recently, the majority of patients received off-pump valve implantation with only a femoral venous and arterial wire in place. For an intraoperatively measured aortic annulus diameter of 21.8 ± 1.8 mm, we implanted a 25 ± 1.6 -mm aortic valve representing an oversizing of approximately 15%. All valves were successfully deployed at the target. In 1 patient, valve embolization into the aortic arch occurred during a second inflation of the balloon owing to a severe paravalvular leakage. On control echocardiography, all other valves showed good hemodynamic function. Repeat valve dilatation was performed because of uneven stent expansion leading to moderate or severe paravalvular leak in 6 (23%) patients. Four (15%) patients retained mild to moderate (I–II°) aortic insufficiency owing to paravalvular leakages. There was no case of substantial intraprosthetic central aortic insufficiency. The mean transaortic valve gradient was 6 ± 2 mm Hg. There were 2 cases of conversion to open surgery including the patient with valve embolization and another patient with a porcelain aorta in whom a type A dissection developed after balloon dilatation. In 2 patients, the left main stem was partially obstructed by the native valve and required stent angioplasty, which was performed successfully. Three patients had severe hypotension after off-pump deployment of the valve requiring transitory CPB support. Two of them fully recovered within 10 and 15 minutes and could be weaned from CPB without difficulties. The third patient was transferred to the intensive care unit with an intra-aortic balloon pump that stayed in place for 2 days and could then be explanted. There was 1 intraoperative death resulting from aortic root dissection during valve deployment.

Figure 2. Perioperative imaging demonstrating 20-mm balloon dilatation of the stenotic aortic valve (A), antegrade delivery, correct positioning (B), and deployment (C) of the prosthesis. A perioperative angiogram demonstrated excellent position and function of the bioprosthesis. There is no evidence of intraprosthetic or periprosthetic insufficiency (D). The left and right coronary ostia are patent (E).

Overall, procedure times accounted for 152 ± 87 minutes. Procedural characteristics are summarized in [Table 2](#).

Hospital Course

Two patients (8%) underwent re-exploration for bleeding ([Table 3](#)). One patient had a wound infection in the groin after femoral cannulation. No patient from this series had a stroke. Thirty-day mortality was 15% ($n = 4$) including the 1 intraoperative death resulting from dissection of the aortic root and 1 death 6 hours after surgery caused by perforation of the right ventricle. Perforation of the right ventricle occurred while the guidewire for venous cannulation was being

advanced through the groin. There were another 2 non-valve-related deaths in patients with multisystem organ failure on postoperative days 3 and 5. The postoperative course in these 2 patients was complicated by leg ischemia after cannulation of the femoral vessels in 1 patient and development of a Leriche syndrome in the second patient. Postmortem assessment in both patients confirmed good prosthetic valve position and function, as well as patent coronary ostia.

Discussion

Reflecting an aging society, patients requiring cardiac surgery are steadily getting older and have more comorbidities.

TABLE 2. Operative results

Aortic annulus diameter (mm)	21.8 ± 1.8
Implanted valve size (mm)	25.0 ± 1.6
23-mm prosthesis (n)	11 (42%)
26-mm prosthesis (n)	15 (58%)
Good valve positioning (n)	25 (96%)
Conversion to sternotomy (n)	2 (8%)
Type A dissection (n)	1 (4%)
Valve migration after repeat valve dilation (n)	1 (4%)
Use of CPB (n)	11 (42%)
Cannulation for CPB (n)	15 (58%)
Implantation off-pump (n)	15 (58%)
Repeat valve dilation (n)	6 (23%)
Severe hypotension (n)	3 (12%)
Intra-aortic balloon pump (n)	2 (8%)
Obstruction of coronaries (n)	2 (8%)
Concomitant stent PTCA (n)	2 (8%)
Operative time (minutes)	152 ± 87
Intraoperative death (n)	1 (4%)

CPB, Cardiopulmonary bypass; PTCA, percutaneous transluminal coronary angioplasty; n (%) is listed for categorical variables; mean ± 1 standard deviation for normally distributed continuous variables.

Calcified aortic stenosis is the most common valvular disease affecting the elderly patient population. To counteract this development, conventional surgical AVR continuously improved over the years with regard to the hemodynamic performance of the implanted valves, additional organ protection measures, and postoperative care adjusted to the specific needs of these patients. Thus, classic surgical AVR still improves symptoms and prognoses in most cases.^{15,16} However, despite all efforts, mortalities may be as high as 20% in patients with left ventricular dysfunction,¹⁷ and some have even been considered nonsurgical candidates.

Percutaneous implantation of a stent type aortic valve became a clinical reality with the first reported successful human case by Cribier and colleagues⁶ in 2002. Subsequently, intense interest has formed toward the development of a catheter-delivered valve for use in patients with critical aortic stenosis declined for surgery. The percutaneous retrograde approach can be problematic because of the obligatory size of the 24F delivery sheath.¹⁸ Many of these elderly patients have coexisting peripheral vascular disease that precludes passing large sheaths or catheters from the groin, around the arch of the thoracic aorta, and across the aortic valve annulus. Moreover, this technique also runs the risk of embolizing atherosclerotic material from the aorta into the distal circulation, including cerebral arteries, causing severe neurologic complications including stroke.¹² We therefore believe that the transapical approach provides a reliable and attractive alternative. The distance of the aortic valve from the left ventricular apex is straight and relatively short, which provides good control over the delivery catheter. This optimal control over the placement of the valve was confirmed in previous

TABLE 3. Postoperative outcome

Length of mechanical ventilation, median (h)	6.4 (IQR: 4.1–8.3)
ICU stay, median, (h)	18.0 (IQR: 12.8–23.4)
Postoperative complications	
Re-exploration (n)	2 (8%)
Stroke (n)	0
Supraventricular arrhythmia (n)	5 (19%)
Transient hemofiltration (n)	3 (12%)
30-day mortality (n)	4 (15%)
Aortic annulus rupture (intraoperative) (n)	1 (4%)
Perforation of the right ventricle (6 hours after surgery) (n)	1 (4%)
Multiorgan failure/Leriche syndrome (POD 3) (n)	1 (4%)
Multiorgan failure/leg ischemia (POD 5) (n)	1 (4%)

POD, Postoperative day; categorical variables are listed as median with intraquartile range (IQR) for nonnormally distributed continuous variables where appropriate.

animal series in which all valves were deployed at the intended target site.^{9,10} Additionally, TAP-AVI carries the potential advantage of avoiding the aortic arch, which in patients with calcified aortic stenosis is frequently subject to atherosclerotic changes.

In the presence of numerous simultaneously evolving strategies for transcatheter-based AVI, a reliable preoperative risk assessment will be critical to compare clinical results of different approaches in the future. Application of the numeric and logistic EuroSCORE allows the preoperative estimate of perioperative risk^{19,20} and has also been used for the purpose of this investigation. We are aware of the observation that specifically the logistic EuroSCORE may overestimate the actual risk to the individual patient.²¹ However, in the absence of a uniformly accepted and validated risk stratification model, we had to use the EuroSCORE estimate to comply with data presented in recent clinical series.^{7,12,14}

The current clinical report confirms that TAP-AVI is feasible, leading to an immediate decrease in the transaortic mean gradient. The total procedure time decreased with increasing experience throughout the study. Currently, a straightforward transapical valve implantation can be routinely performed in less than 80 minutes. Initially, it was our belief that circulatory support with CPB may represent a safer alternative to brief rapid cardiac pacing in patients with severe aortic stenosis and left ventricular hypertrophy inasmuch as low cardiac output may lead to myocardial ischemia and subsequent hemodynamic instability. With gained clinical experience, we felt more comfortable to identify patients who may be at higher risk for hemodynamic deterioration before deployment of the valve. Typically, patients who had stable perioperative hemodynamics and responded well to low doses of norepinephrine by an acute increase in systolic arterial pressure tolerated rapid pacing without difficulties. Furthermore, it was helpful to

hemodynamically “prime” patients by increasing the systemic arterial pressure before rapid ventricular pacing during valve deployment with low doses of norepinephrine. In our experience, a targeted systolic peripheral arterial pressure of 120 to 140 mm Hg seemed to be ideal.

In summary, initial results of the transapical approach for AVI in a cohort of older and high-risk surgical patients at our institution can be considered encouraging. Notably, permanent neurovascular complications were absent as compared with the reported experience with endovascular transcatheter-based AVI. Future routine clinical application of this emerging approach will be dependent on further technical improvements and gained operative experience, leading to a decreased mortality and morbidity with short- and long-term results comparable with conventional AVR surgery, which remains the gold standard.

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